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Optoelectronic Workshops: Liqu	id Crystals for	Laser Appli	cations		
(12 PERSONAL AUTHOR(S)					
Stephen Jacobs, University of	Rochester; and J	luergen Pohl	mann, NVEO		
(13e) TYPE OF REPORT 13b. TIME CO	OVERED TO	14. DATE OF REPO		h, Day) 15. PA	AGE COUNT
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academic/ governmen	it interactions in t	he field of ac	lyanced elec	ctro-optics	as part of
the Army sponsored	University Res	earch Initia	tive. The	worksho	ps are a
collaboration betwee University of Rochste	n the Center to	Copto-Electi	ronic System	ms Researc	in at the
Vision and Electro-O	ntics Ft Relunir	Virginia R	ne U.S. Arn	ny Center	for Night
technology status and	dialogue it is ho	ped that this	baseline wil	ll serve all i	nterected
parties towards pro-	viding a solution	to high p	riority Arm	iv require	ments
kesponsible for progra	am and program (execution are	: Dr. Nichola	s George,	University
of Rochester (ARO-ŪR	i) and Dr. Rudy Bu	iser, NVEOC.	-		· · · · ·
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The Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS

IV

LIQUID CRYSTALS FOR LASER APPLICATIONS

May 11, 1988

sponsored jointly by

ARO-URI Center for Opto-Electronic Systems Research
The Institute of Optics, University of Rochester

OPTOELECTRONIC WORKSHOP

ON

LIQUID CRYSTALS FOR LASER APPLICATIONS

Organizer: ARO-URI-University of Rochester and Center for Night Vision and Electro-Optics

- 1. INTRODUCTION
- 2. SUMMARY -- INCLUDING FOLLOW-UP
- 3. VIEWGRAPH PRESENTATIONS
 - A. Center for Opto-Electronic Systems Research
 Organizer -- Stephen Jacobs

A Dozen Liquid Crystal Device Concepts Stephen Jacobs

Nonlinear Optics and Laser Damage Resistance of Liquid Crystals
Ansgar Schmid

Ferroelectric Liquid Crystals Kenneth Marshall

B. Center for Night Vision and Electro-Optics Organizer -- Juergen Pohlmann

Historical Perspective: Liquid Crystal Research at Fort Belvoir Wolfgang Elser

Current Liquid Crystal Research Juergen Pohlmann

Liquid Crystal Electro-Optic Shutter James Miller

- 4. LIST OF REFERENCES
- 5. LIST OF ATTENDEES
- 6. DISTRIBUTION



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1. INTRODUCTION

This workshop represents the fourth of a series of intensive academic/government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI) and Dr. Rudy Buser, NVEOC.

2. SUMMARY AND FOLLOW-UP ACTIONS

a. IR Light Scatterer:

Based upon viewgraphs provided by J. Miller and subsequent discussions, we will consider liquid crystal and other technologies which might have the required performance. We will discuss our concepts further with him to define, if possible some activity which we might jointly pursue (within our resource base) to construct and characterize an alternative device concept.

b. Optical Power Limiter:

Perhaps Night Vision and Electro-Optic Center wants to organize a more narrowly defined meeting to address their specific needs compared to objectives already being pursued by the NADC and the BAA. We would be happy to help organize and participate in such a meeting.

c. Holographic Photopolymer:

We will obtain more information from Dr. Thomas Stone (U of R) to see if there is some input we can make to the doping of liquid crystals into porous polymer films. Mark Norton (NV&EOC) has an interest in this.

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH A DOZEN LIQUID CRYSTAL DEVICE CONCEPTS

A Dozen Liquid-Crystal Device Concepts



- (1) Wave Plate
 - (2) Polarizer(3) Isolator
- (4) Beam Splitter(5) Mirror(6) Notch Filter
- (7) Attenuator
- (8) Beam Apodizer
- (9) (Bistable) Beam Deflector(10) Shutter/Chopper(11) Power Limiter(12) Light Scatterer

Nematic Class: Device Application True Zero-Order Wave Plates



Quarter Wave Plate

circularly polarized output 300 ton = 1/4 linearly polarized L.C. cell light, path

Sapphire Plastics Mica Quartz

Properties of Interest

- Spectral transmission
- Refractive index
- Birefringence
- Thickness for λ/2 plate
- Accuracy of retardance
- Uniformity of retardance
 - Angular sensitivity
- aser-damage resistance >6 J/cm² (1 ns, 1000 nm)
 - Optical quality
- **Aperture limits**

Liquid Crystals

1.45-1.80 UV-IR

0.035 - 0.280

1-4 µm

±1% with blending

±1.5 nm across 100 mm

weak

substrate defined

none

Circular Polarizer for Pockels' Cell, E-O Switching

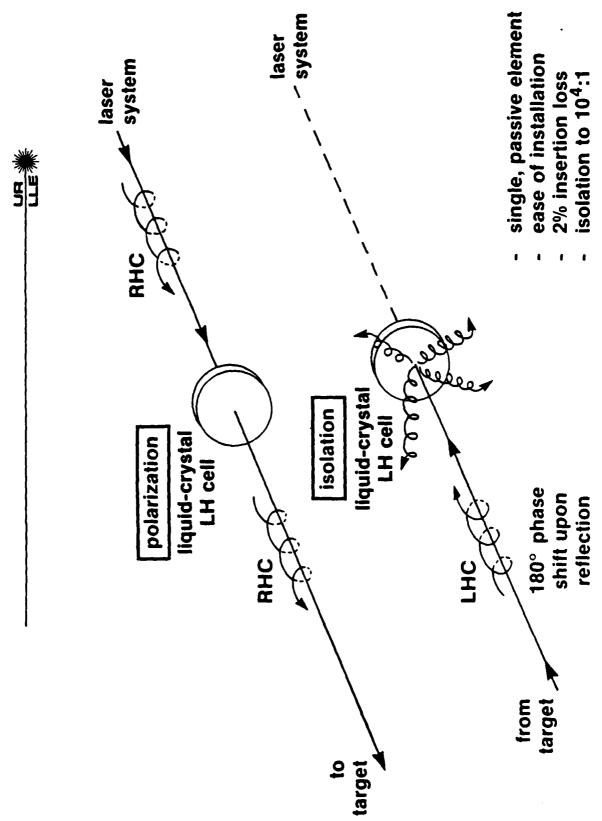
Alignment insensitivity, ±10° High contrast on/off, 10⁴ O.D. High transmission, 98% Variable bandwidth, 20 nm to 200 nm Large aperture Attributes cholesteric cholesteric 3 Ξ Ħ I 10=7. E-0 cell E-O cell RH cholesteric RH cholesteric LH circular

G1392

LH circular

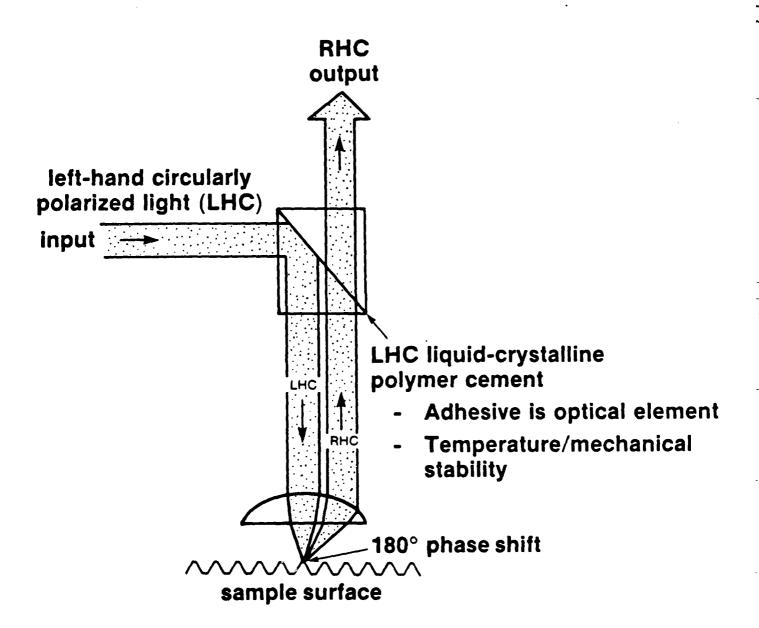
- V = VAIR

Dual Role for Liquid-Crystal Polarizers: Polarization and Isolation



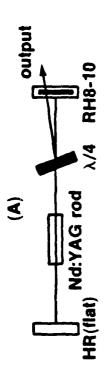
Beam-Splitter Liquid-Crystal-Polarizing Prism

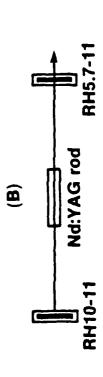


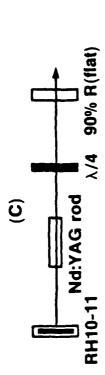


Liquid-Crystal Mirror Laser Resonator Configuration





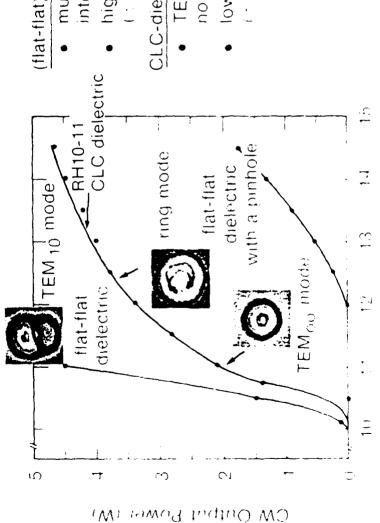




- Modification to a Control Laser Corp. model 256 Nd:YAG head (cw)
- (A) CLC (thick)-dielectric: output via Fresnel reflection
- (B) CLC (thick)-CLC (thin): output though thin partial reflector demonstrated
- (C) CLC (thick)-diefectric: output through 90% R
- Performance improvements
- TEM_{oo} output without pinhole
- Reduced angular sensitivity

Comparison of CLC Resonator with Dielectric Resonator





(flat-flat) dielectric resonator

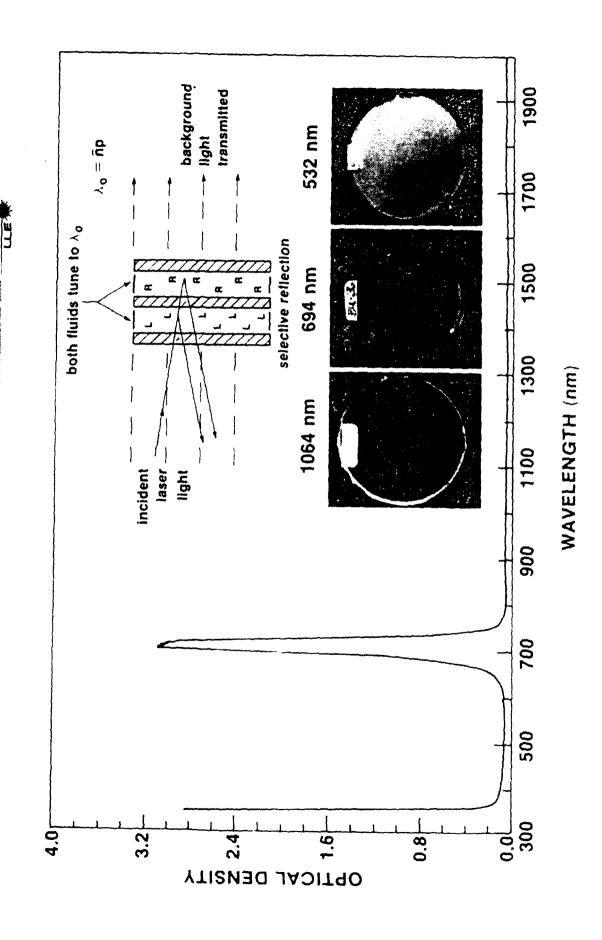
- multimode output profile with no internal aperture
 - high sensitivity to mirror tili

CLC-dielectric resonator

- TEM_{oo} mode operation with no internal aperture
- low sensitivity to mirror tilt1.8 arcsec)

de Lamp Current (A)

LIQUID-CRYSTAL LASER-BLOCKING FILTER



Optical Radiation Attenuator



United States Patent [119]

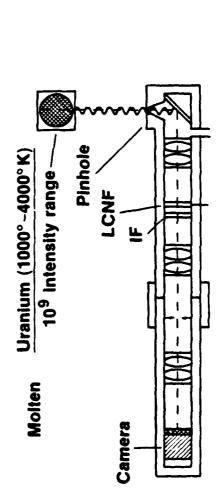
Rushford

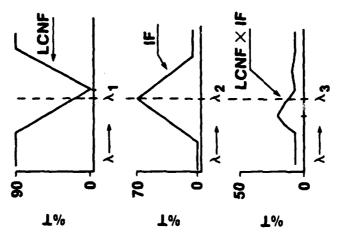
[11] Patent Number: 4,726,660

Date of Patent: Feb. 23, 1988 **(45)**

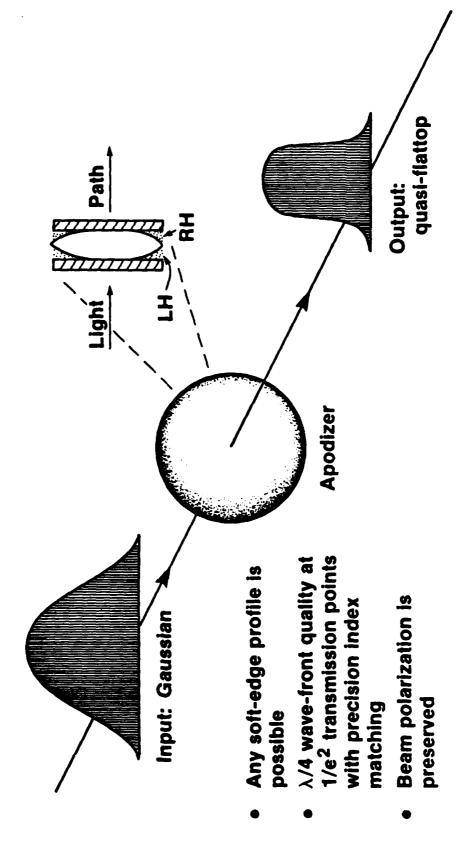
TECHNIQUE FOR COMPRESSING UTILIZING A SPECIFICALLY DESIGNED LIQUID-CRYSTAL LIGHT INTENSITY RANGES NOTCH FILTER 3

Inventor: Michael C. Rushford, Livermore, CA [3]

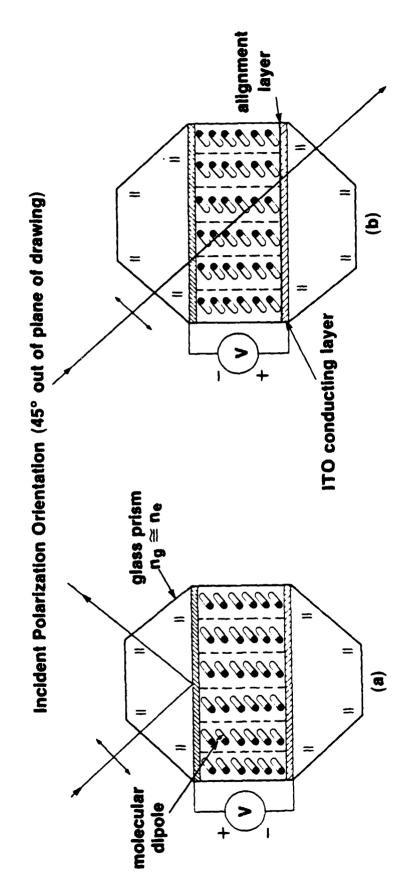




Liquid-Crystal Laser Beam Apodizers



Two-Position Bistable Beam Deflection Device Using fTIR in Ferroelectric Chiral Smectic C Mesogens

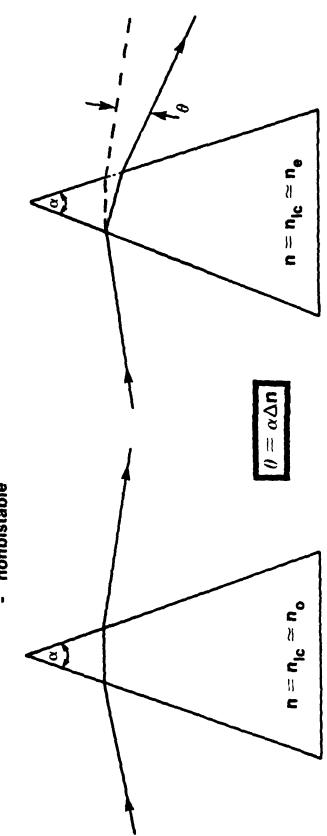


(a) Incident radiation experiences no, allowing TIR. (b) Reversal of field polarity causes incident radiation to experience ne, resulting in ITIR.

Liquid-Crystal Wedge Multiposition Beam Deflector Concept

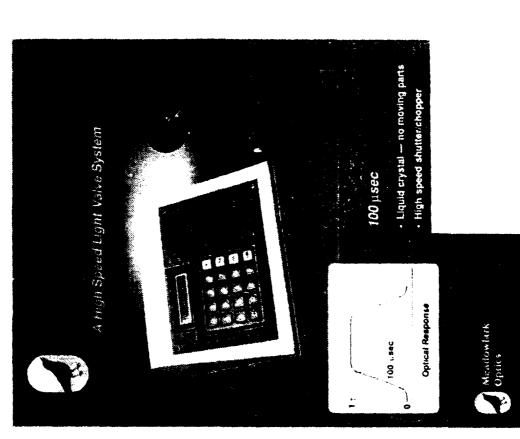


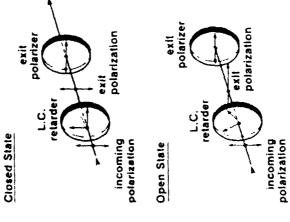
- Several possible modes of operation
- bistable
- bistable with tunable birefringence around two bistable positions
- nonbistable



where $\theta =$ deflection angle (several tenths of a degree) $\alpha =$ cell wedge angle (0.1–1.0 degrees) $\Delta n =$ change in refractive index due to field-induced director reorientation (as large as 0.2)



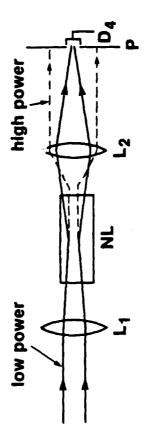




Optical Power Limiter Geometries

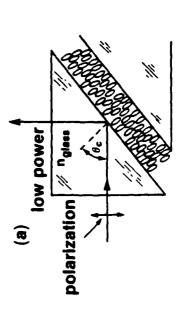


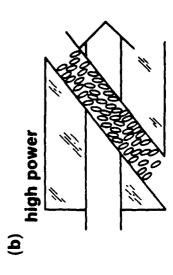
Self Focusing



After Solleau et al., IEEE J. Quantum Electron. QE-19, 731 (1983).

Total Internal Reflection





Polymer-Dispersed Liquid Crystals Induced Light Scattering

United States Patent

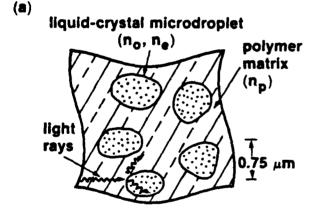
[11] Patent Number: 4,556,289

Fergason

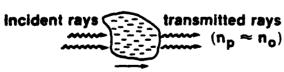
Date of Patent: Dec. 3, 1985

LOW BIREFRINGENCE **ENCAPSULATED LIQUID CRYSTAL** AND OPTICAL SHUTTER USING SAME

Inventor: James L. Fergason, Kent, OH







applied electric field

From N. A. Vaz and G. P. Montgomery, Jr., J. Appl. Phys. 62, 3161 (1987).

CLEO TUESDAY, 26 APRIL 1988 **Anaheim Convention Center**

TuT, Light Manipulation with **New Materials**

4:30 PM

TuT1 Observation of Optical Limiting Using Polymer-Dispersed Liquid-Crystal Thin Films.

David M. Pepper, J. David Margerum, Anna M. Lackner, Elena Ramos, Hughes Research Laboratories. Optical limiting using polymer-dispersed liquid crystals is demonstrated. These heterogeneous mixtures are index matched at low intensities, and behave as diffuse scatterers in the nonlinear regime due to optical reorientation of the liquid-crystal dispersant.

NONLINEAR OPTICS AND LASER DAMAGE RESISTANCE OF LIQUID CRYSTALS CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH

Two Dominant Physical Mechanisms for Third-Order Optical Nonlinearities in Liquid Crystals



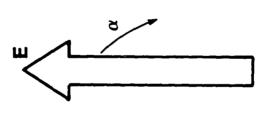
Orientational

based on large birefringence: $\Delta n = 0.1-0.2$

Electronic

based on electron delocalization

Linearly polarized external field induces torque

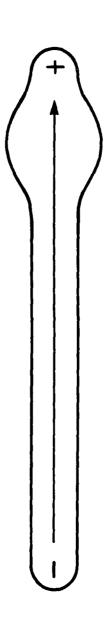


Result: Field-driven molecular reorientation (Freedericksz effect)

Mechanism of Orientational Optical Nonlinearity in Liquid Crystals



Donor/acceptor (substituent) pairs on liquid-crystal core introduce electric dipole moment



The Dynamics of the Freedericksz Transition Is Driven by the External Forces and Elastic Restoring Forces



Free energy density:

$$\mathbf{F} = \int_{\mathbf{V}} \mathrm{d}\mathbf{r} \frac{3}{2} \left\{ \kappa_{11} \left(\nabla \cdot \vec{\mathbf{n}} \right)^2 + \kappa_{22} \left[\vec{\mathbf{n}} \cdot (\nabla \times \vec{\mathbf{n}}) \right] + \kappa_{33} \left(\vec{\mathbf{n}} \times \nabla \times \vec{\mathbf{n}} \right)^2 \right.$$
elastic part
$$+ \left(\overrightarrow{\mathbf{E}} \cdot \overrightarrow{\mathbf{D}} + \overrightarrow{\mathbf{B}} \cdot \overrightarrow{\mathbf{H}} \right)$$

Maxwell:

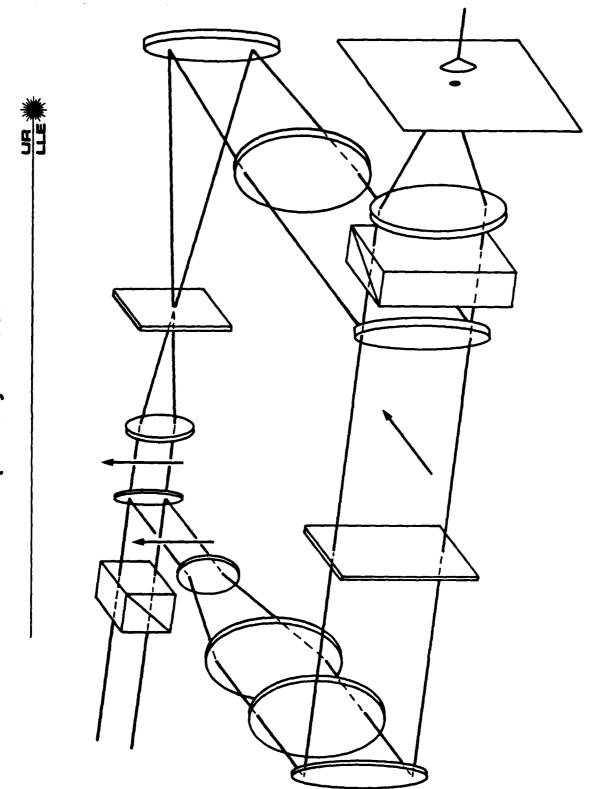
electromagnetic part

$$\overline{\mathbf{D}}=\epsilon(\alpha)\;\overline{\mathbf{E}}$$

Euler-Lagrange:

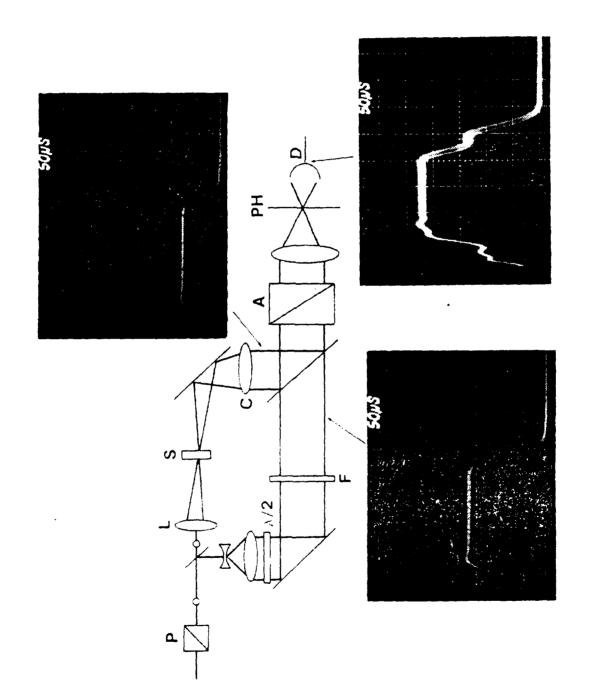
$$\delta_{xx}^2 \alpha + \delta_{zz}^2 \alpha + A \frac{\sin \alpha \cos \alpha}{(1-B \sin^2 \alpha)^{3/2}} = 0$$

Mach-Zehnder Interferometer for Self-Phase-Modulation Measurements in Thin Liquid-Crystal Cells



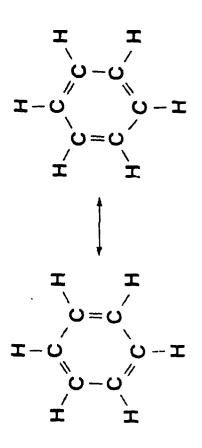
fermotral שוויים ווייחסליים אפר היספרה לפריה אפריה שפריה אפריה שפריה אפריה שפריה אפריה אפיה אפריה אפר

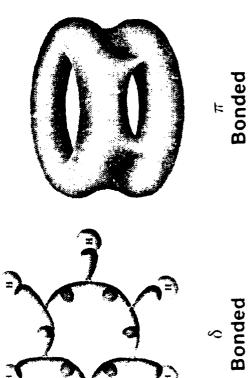
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Delocalized Orbitals in Aromatic Systems





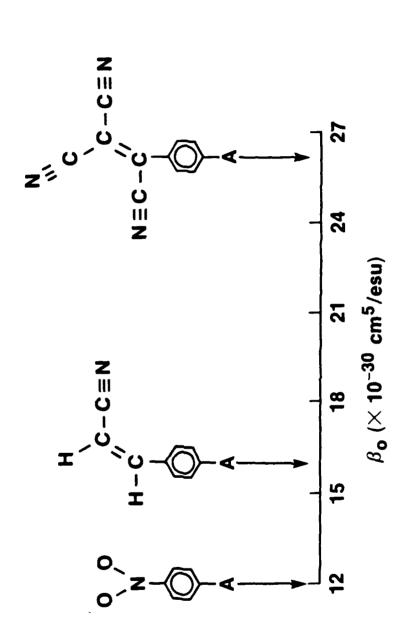


Electronic Molecular Hyperpolarizability Is Strongly Enhanced by π -Electron Delocalization



Second-Order Example:

frequency conversion at 1.3 μm (AT&T Bell Laboratories)



Damage and Degree of Conjugation in Liquid Crystals We Demonstrate The Link Between 1053-nm Laser



- Use both monomeric and polymeric systems
- Prepare samples of identical pathlength (\sim 100 μ m)
- Monitor impurity trace levels
- Limit use of alignment layers
- Test at identical wavelength and pulse length

G2315

Fully Saturated Electron System Raises 1053-nm Damage Threshold in Liquid Crystals



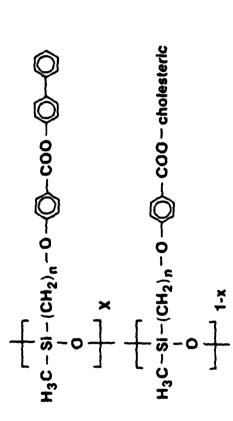
(800-ps pulse length, 100- μ m path length, 5-mm spot size, linear polarization) Damage Threshold Comparison of Two Model Compounds

Compound	K-15	ZLI-1185
Structure	сн ₃ -(сн ₂) ₇ -@-си	$CH_3-(CH_2)_7$ C CN
Mesophase	nematic (22°C)	nematic (62°C)
1-on-1 (J/cm ²)	9.6±2.4	>16.6
N-on-1 (J/cm ²)	5.4±1.3	14.6±0.5

Liquid crystals unaligned; alignment layers usually lower threshold

for given spot size, transport optics damage at $20\ \mathrm{J/cm^2}$

Reduced Conjugation Volume Density Improves Laser Damage Threshold In Chiral Nematic Polymer



Weight % Cholesteric	Tuned Peak Wavelength (nm)	Film Thickness (μ m)	1-on-1 Threshold (J/cm^2) at 1054 μ m/1 ns
14	1170	108	0.8±0.1
21	760	104	2.2±0.4
35	450	84	5.1±1.2

Summary



- Large, moderate-speed optical nonlinearities available through Freedericksz reorientation in liquid crystals
- materials that are highly saturated (free of conjugated bonds) When laser damage is a potential problem, choose organic
- There may be trade-offs between high damage threshold and other optical, mechanical or thermal properties
- Measured damage thresholds compare well with those of standard coatings

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH FERROELECTRIC LIQUID CRYSTALS

Presentation Format

- Background-dielectric E-O effects in nematic liquid crystals
- Origin of ferroelectric E-O effects in chiral smectic liquid crystals
- Current status of ferroelectric liquid-crystal device technology
- Materials considerations for ferroelectric liquid-crystal devices

Electro-Optic Devices Based on Dielectric Effects in Nematic Liquid Crystals



- Wide application in information display area
- low operating voltage
- low power consumption
- relatively easy to fabricate
- good contrast in strong ambient lighting
- Disadvantages for high-speed optical processing/switching applications
 - slow response times (10-500 ms)
- static electric field required to reorient and stabilize director (not bistable)
- electro-optic response not field linear (strong threshold effect)

Ferroelectric Liquid Crystals Advantages



- Fast response 0.5 μs demonstrated, nanosecond response times predicted
- Bistable switching effect pulsed dc drive
- Optic axis orientation determined by polarity of applied electric field
- Field-linear E-O response possible under certain conditions
- Large E-O response for thin cell spacings

Classification of Ferroelectric Smectic Phases



GROUP I: Smectic Liquid Crystals (C*, I*, F*)

No long-range periodic ordering

Smectic C*: random ordering within layer

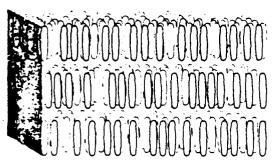
Smectic I* and F*: hexagonal close packed within layer

GROUP II: Anisotropic plastic crystals (J*, G*, K*, and H*)

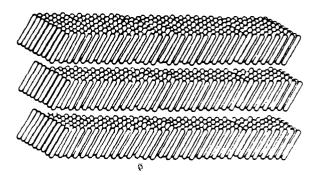
Long-range ordering of molecules in three dimensions

Structures in Smectic Class

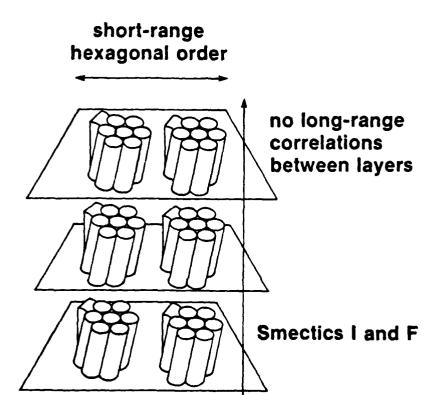


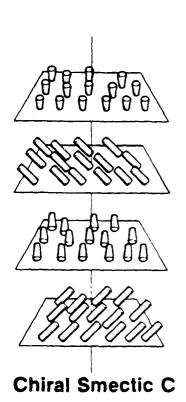


Smectic A



Smectic C





Origin of Ferroelectric Effects in Chiral Smectic Liquid Crystals

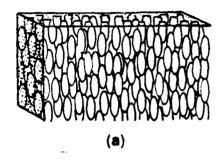


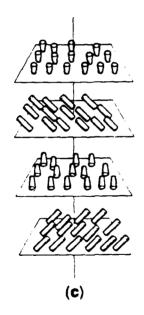
dipole moment per unit volume), which is reversible by an external Ferroelectric Materials: defined as materials that over a certain temperature range possess a spontaneous polarization (or net electric field

Dipolar ordering can arise in any system having a layered structure, tilt, and chirality of its constituent molecules (R. B. Meyer, Harvard University, 1975)

Chiral smectic liquid crystals fulfill these requirements.

Diagram 1

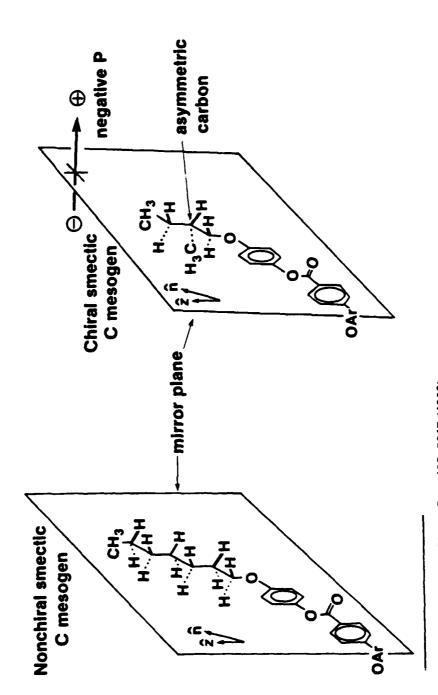




$$H_{11}C_5$$
 \longrightarrow U_{μ} U_{μ} U_{μ} U_{μ} U_{μ} U_{μ}

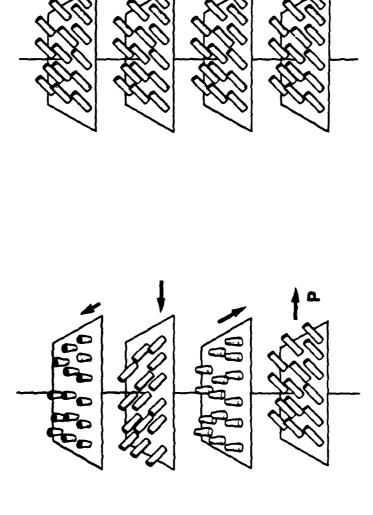
$$C_2H_5$$
— $\dot{C}H$ — CH_2O $\bigcirc \dot{C}$ $\bigcirc O$ $\bigcirc O$

Chiral Centers Cause Spontaneous Formation of Permanent Dipoles by Reducing Molecular Symmetry



Walba et al., J. Am. Chem. Soc. 108, 5217 (1986).

Chiral Smectic Liquid Crystals Must be Untwisted to Show Ferroelectric Properties



(a) twisted structurenet average dipole moment = 0no bulk ferroelectric properties.

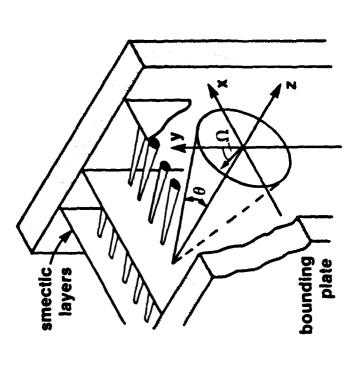
(b) untwisted structure nonzero average dipole ferroelectric properties exhibited.

Methods of Untwisting the Chiral Smectic Helix



- Electric-field unwinding
- Magnetic-field unwinding
- Mixing of materials with opposite chirality
- Unwinding by surface forces and thin cell spacings

Elastic Unwinding of the Chiral Smectic C Helix by Surface Forces and Thin Cell Spacing



 $\theta=$ molecular tilt angle within layer $\Omega=$ angle of tilt of molecule off surface (splay)

M. Handschy, N. Clark, and S. Lagerwall, Phys. Rev. Lett. 51, 471-474 (1983).

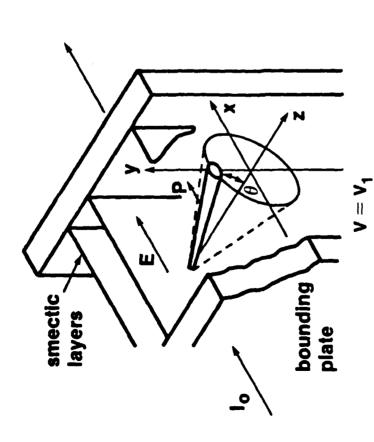
Surface-Stabilized, Ferroelectric, Liquid-Crystal Device (SSFLC)

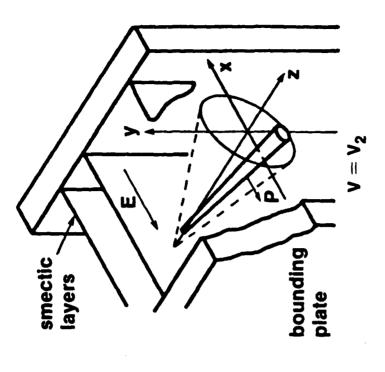


- Cell thickness < pitch, bistable
- Most widely investigated
- Reasons:
- fast response (0.5 μs demonstrated)
- bistability; controlled by boundary conditions
- large electro-optic effect (20°-60° rotation of an uniaxial material with $\Delta n = 0.2)$
 - slow development; lack of materials with room-temperature ferroelectric phases

Director Reorientation in the SSFLC Device



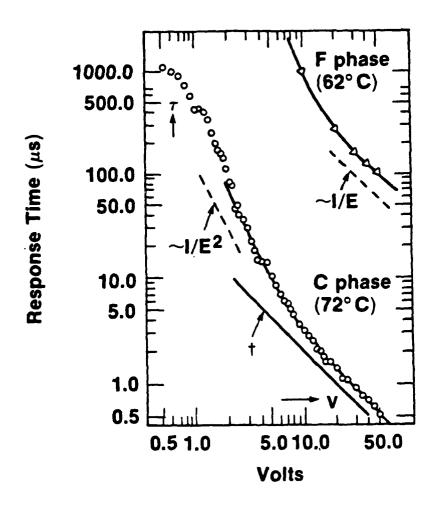




- Angle of deflection = 2θ (θ = molecular tilt angle within smectic layer)
- Typical values for θ are between 22.5° and 45° (material dependent)

Electro-Optic Response of SSFLC Device (1.5-μm thick) Using HOBACPC



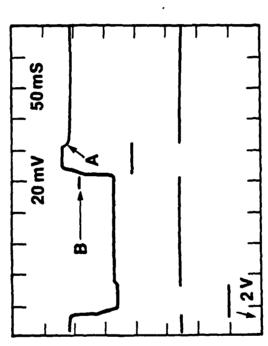


† Calculated value for an infinite pitch ferroelectric C in the high field limit.

N. Clark and S. Lagerwall, Recent Developments in Condensed Matter Physics 4, 317 (1981).



cell spacing = 1-2 μ m; response time = 1 ms



A = field-off relaxation top tra B = bulk-surface switching bottor transition

top trace = optical response bottom trace = 3-V, 5-ms

applied pulse

J. Patel, Appl. Phys. Lett. 47, 1278 (1985).

Materials Considerations



- Desirable properties
- high chemical stability
- radiation hardness
- broad-range ferroelectric phase (room temperature)
- large spontaneous polarization (low operating voltage)
- long intrinsic helical pitch (> 5 µm) (fast response)
- smectic A chiral smectic C phase transition
- Bulk of investigations employed DOBAMBC and HOBACPC
- easy synthesis
- · large spontaneous polarization
- not suitable for room-temperature devices

Chiral Smectic C Mesogens



Structure

S; Range

$$C_{10}H_{21}O- \bigcirc\bigcirc\bigcirc -CH=N- \bigcirc\bigcirc\bigcirc -CH=CH-C-O-CH_{2}-HC^{+}_{C}$$

85-90°C

DOBAMBC

$$C_6H_{13}O- \bigcirc\bigcirc\bigcirc -CH=N- \bigcirc\bigcirc\bigcirc -CH=CH-C_0-CH_2-HC^*$$

62-74°C

HOBACPC

100-134°C

disubstituted benzalazine

с₈H₁₇-{О}-СОО-{О}-СН₂ССН₃

CE-8

70.3-87°C

Recent Materials Advances



- Eutectic mixtures of existing chiral smectic C materials
- Nonchiral smectic C mixtures doped with chiral smectic C additives
- New, more stable chiral smectic C mesogens with ferroelectric phases near room temperature
- Commercial availability of room-temperature chiral smectic C mixtures (June 1986)

SURVEY OF COMMERCIALLY AVAILABLE CHIRAL SMECTIC C MESOGENS



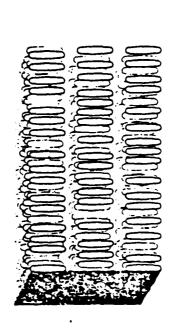
Vendor	Catalog #	Single substance (S) or mixture (M)	Chiral Sc* Range (°C)	Tilt Angle (θ) at 20°C, Degrees	Δn @ 589 nm, 25°C
E. Merck	ZLI-3488	X	-30 to +61	25.5	1
:	ZLI-3489	M	-30 to +65	29.0	:
*	ZLI-3654	M	-30 to +62	25.0	í
:	ZLI-3774	M	-30 to +62	25.5	í
:	ZLI-3775	M	-30 to +61	26.0	í
:	ZLI-4003	M	-20 to +62	23.0	ſ
врн	SCE-3	×	0 to +74	25.0	0.17
:	SCE-4	×	0 to +57	23.0	0.17
=	SCE-5	¥	-15 to +63	22.5	0.18
•	SCE-6	W	-15 to +63	23.5	0.18
Displaytech	W7	S	+9 to +27	23.0	0.105
*	W81	S	+15 to +56.5	23.0	0.105
=	W37	S	+25 to +37.5	23.0†	0.105
=	W82	S	+30.5 to +70.5	23.0†	0.105
*	W46	S	+64 to +80	23.0†	0.105
z.	MDW7	S	+25 to +45.8	23.0†	0.105

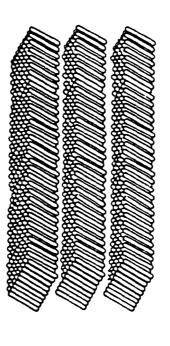
† Values estimated from mixture data.

Effect un Electroclinic

Garoff and Meyer — 1978(4) Coordinated tilt of molecules within layer under influence of an electric

Occurs in smectic A materials containing chiral centers-hindered rotation. Response time << Fredericks transition in nematics.



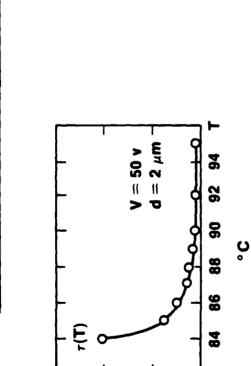


0 = A

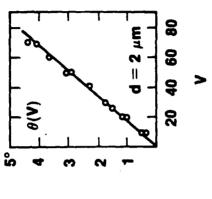
V > V

S. Garoff and R. B. Meyer, "Electroclinic Effect at the A-C Phase Change in a Chiral Smectic Liquid Crystal," Phys. Rev. A 19, 338 (1979).

Electroclinic ("Soft Mode") Effect - Optical Response



3



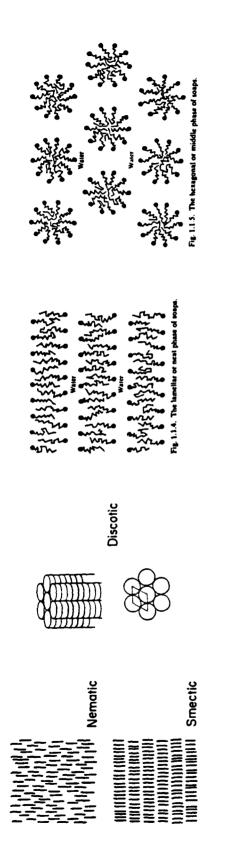
Critical slowing down of switching speed on approaching the A'-C' transition. The material is DOBA-1-MPC, in the A' phase (83°C to 102°C).

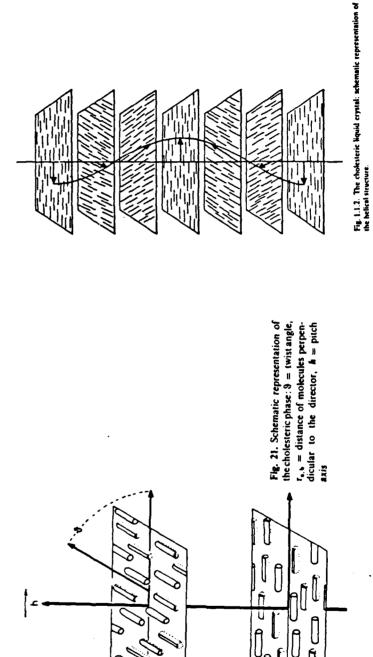
Linearity in the tilt angle response versus applied voltage in DOBA-1-MPC at 86°C.

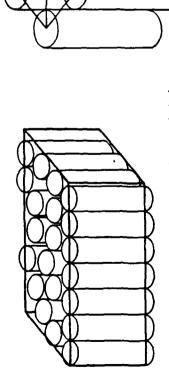
- Achievable response: < 100 ns with high-temperature compounds < 1 μs at room temperature
- Approximately 10-100 times faster than SSFLC mode

S. T. Lagerwall et al., Mol. Cryst. Llq. Cryst. 152, 503-587 (1987).

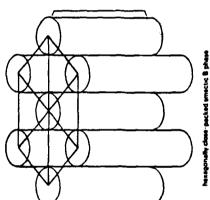
HISTORICAL PERSPECTIVE: LIQUID CRYSTAL RESEARCH AT FORT BELVOIR **CENTER FOR NIGHT VISION AND ELECTRO-OPTICS**



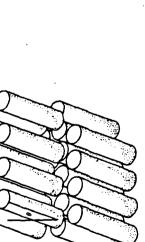




Disordered arrangement of molecular centres in a smectic A phase.



The packing artangement of molecules in a layer in the smeetic E phase (b>a)—see also Fig. 5.1



Structure of the smecric C phase; there is no regular arrangement of the molecular centres in the planes of the unstructured layers. Tilt angles (8) may range upwards from $\lesssim 10^\circ$.

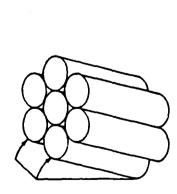
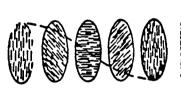


Figure 6.1 Structure of the Sy phase.



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CHOLESTERIC

no long-range Correlations Detween layers

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C-SHORT RANGE ORDER LF-SHORT RANGE HEXAGONAL ORDER

TILT ORENTATIONAL AND POSITIONAL ORDER POLYCRYSTAL SMECTOID CRYSTALS G'H(J,K* LONG RANGE

Figure 1. The structures of the cholesteric, ferroelectric smeetic liquid crystal, and ferroelectric crystal (smeetoid) phases.

Hexagonal close-packed molecules in the smectic G phase

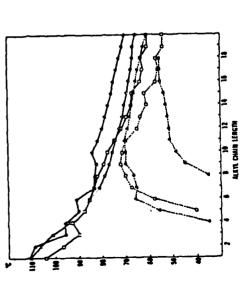


Fig. 19. Transition temperatures of carbonates. Transitions as defined in Fig. 17. ∆, Cholesteryl alkyl carbonates, V; □, cholesteryl S-alkyl thiocarbonates, VI; ▲, S-cholesteryl alkyl thiocarbonates, VI; A, S-cholesteryl

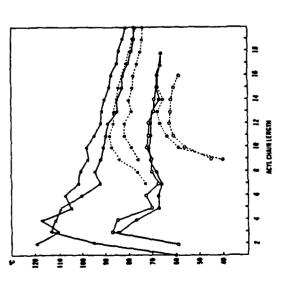


Fig. 17. Transition temperatures of alkanonies. Solid lines: cholesteric-inotropic phase transitions; broken lines: smectic-cholesteric phase transitions. Δ., Cholesteryl alkanonies, 1; Δ., S-cholesteryl alkanonies, 11; Ο, δα-chokstan-3β-yl alkanonies, XIV; Φ, δα-cholester-1β-yl alkanonies, XIV; Φ, δα-cholester-1β-yl alkanonies, 73.

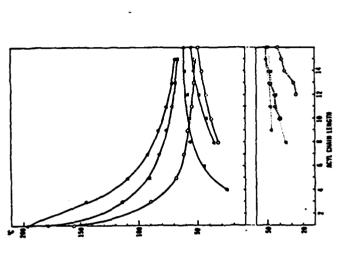
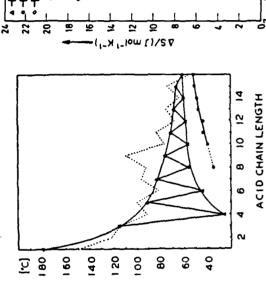
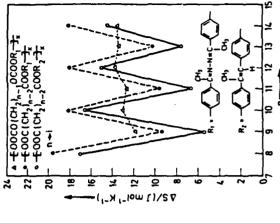


Fig. 18. Transition temperatures of a-phenylaikanoates. Transitions as defined in Fig. 17.

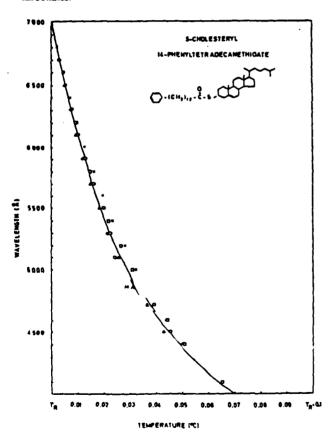
A. Cholesteryl a-phenylaikanoates, III; A. S-cholesteryl a-phenylaikanethioates, IV;

O, 5a-cholestan-36-yl a-phenylaikanoates, XV.





*	I	11	111	IV	V	VI	VII	XIV	χv	XVI	XVII
5	_		_	_			56.3~56.0				
6	_		_	_	_	56.0-53.0	68.5~68.0	_	_		_
. 7		72.7-71.5	83.0-82.0			68.0-67.0	64.3~64.1	_	_	_	34.3-31.3
8	-	74.0-72.9	_	-	41.0-37.3	_	67.3-66.7	_			47.8-47.0
9	77.9-76.5	_	-	50.3-48.1	50.0-45.5	_	_	_	_	_	52.4-51.9
10	77.1-76.1	_	39.5-39.3	-	51.0-49.4	_	70.2-70.1	_	_		55.4-55.2
11	-	_	47.0-44.2	49.9 48.7	52.3 51.5		70.5	61,9-61.1		39.5 39.2	
12	-		44.6-44.3		53.0-52.1	_	70.5	63.6-63.1	26.6-26.1	43.5-42.1	_
13	-	_	50.0-48.1	51.1-49.8	53.1-52.5	_	68.7	_	_	43.6-42.6	_
14	-	_	48.7-48.3	47.35	53.9-52.9	_	67.8	_	36.0-35.6	-	_
15			53.0-52.0	52.4-51.6	54.9-54.1		66.5	_	_	41.4-40.3	_
16	-	_	51.7-51.3	49.6-49.4	55.7-55.0	_	65.4	_	44.0-41.7	_	_
17	-	_			56.2-55.6		64.5	_		_	_
. 18		_			56.4-55.8	57.8-57.4	63.2-63.1	_		_	_
19		_			55.1-49.9	-	62.5-62.3	_		_	_
20		_			- '	57.0-56.0	60.6-60.4	_		_	_



Vig. 23, Wavelength of maximum selective reflection as a function of temperature. Naterial: 5-cholesteryl (4-plenyltetradecanethouse. κ, Data set 1), Li, quas set 11, measured on same day on same sample as set 1; Δ, data set 11, second sample, cooled at 2 m²/min, measured K days after set 1; Δ, data set 1V, third sample, cooled at 5 m²/min, measured 9 days after set 1 (cf. 1nhle IX). [Reproduced from Ennulat et al., Mol. Cryst. Liquid Cryst. 26, 245 (1974), with permission.]

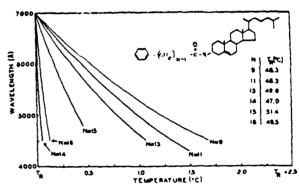


Fig. 24. Wavelength of maximum selective reflection as a function of temperature. Materials: S-cholesteryi ω-phenylalkanethioates.

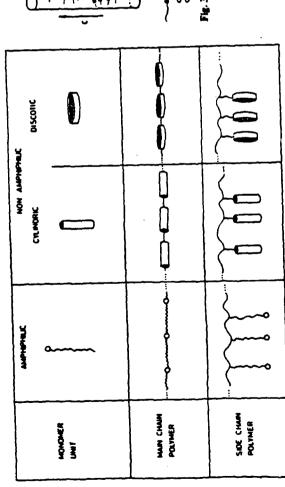
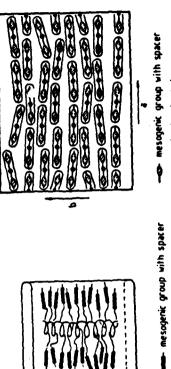


Fig. 1. Classification of liquid crystalline monomers and polymers

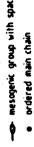






-co- mesogenic group with spacer

30-30-30-30-30-





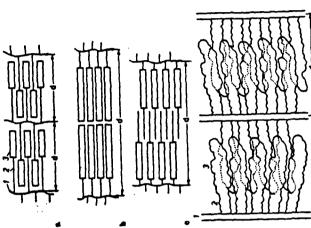


Fig. 18m-d. Schemes of side chains packing of macromokeutes in S_A-mesophase of orientated LC potents; (a) one-layer packing; (b) two-layer packing; (c) packing with overlapping of alkyl "tails"; (d) packing with partial overlapping of matogenic fragments (side chains are designated by van-der-Wash radial; — main chain; 2 — spaces; 3 — mesogenic group (Side groups of neighbouring macromocules (in the cases a, c and d) are arranged in different planes parallel to the plane of the figure)

CURRENT LIQUID CRYSTAL RESEARCH SPONSORED BY NVEOC CENTER FOR NIGHT VISION AND ELECTRO-OPTICS

Liquid Crystals in R&D Tasks



RFP N62269-87-R-0218 Naval Air Development Center under solicited by

Tri-Service Contracts awarded to be awarded

Institute of Optics / Laboratory for Laser Energetics K. L. Marshall, S. D. Jacobs, and coworkers The University of Rochester

Optical Shields, Ltd.
 J. L. Fergason and coworkers

- Hughes Research Laboratories S. T. Wu and coworkers

Honeywell
 Physical Sciences Center
 S. Jenekhe and coworkers

Liquid Crystals in R&D Tasks



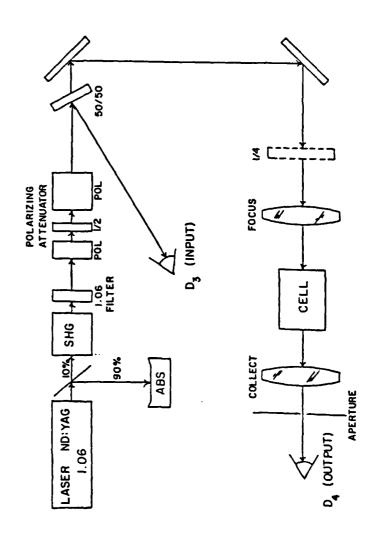
to be awarded under BAA issued by DARPA / Army / CNVEO

- Kent State University
 Liquid Crystal Institute
 M. A. Lee, J. W. Doane, and coworkers
- The Pennsylvania State University College of Engineering 1. C. Khoo
- Optical Shields, Ltd.
 J. L. Fergason and coworkers
- HoneywellSystems and Research CenterS. K. Lo and coworkers

Nonlinear Measurements

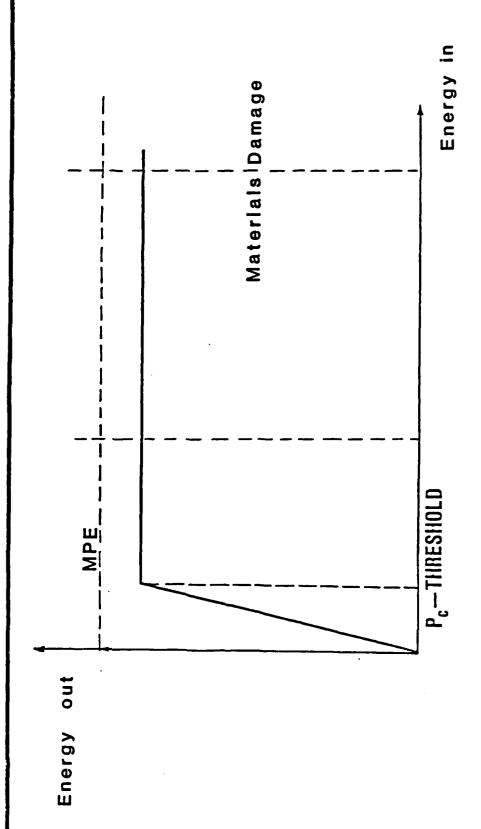


Center for Research in Electro-Optics and Lasers M. J. Soileau, E. W. Van Stryland, and coworkers The University of Central Florida



Power/Energy Limiter, ideal





6

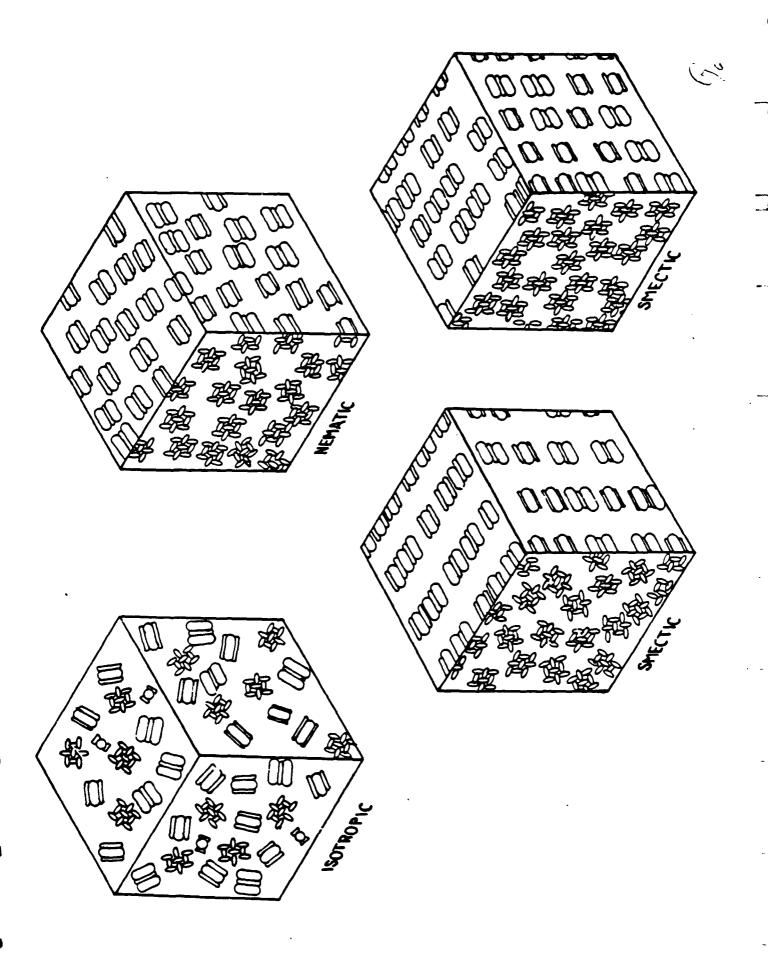
PHASES OF MATERIAL

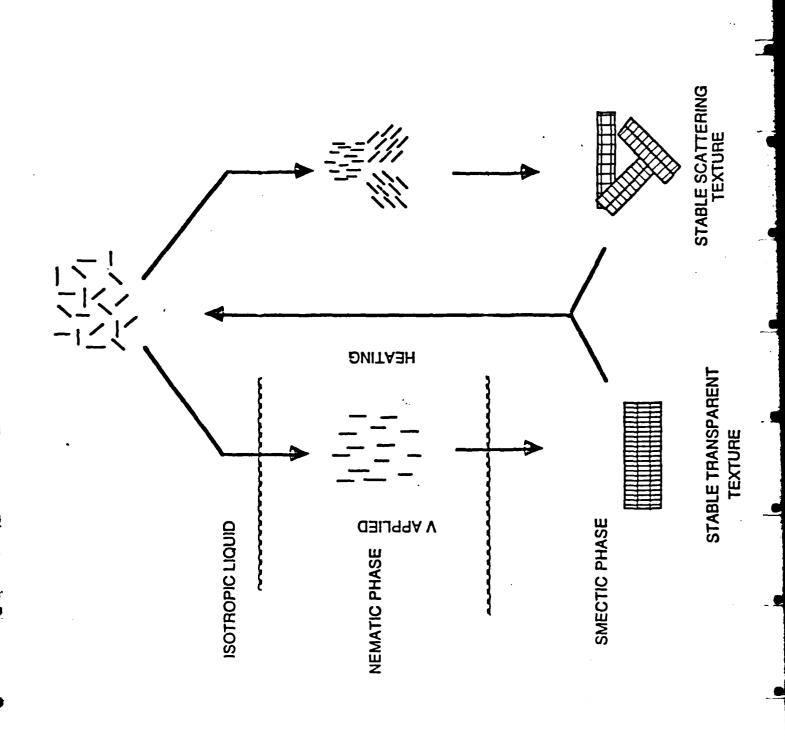
Liquid Crystal Phase

leotropic Liquid	Nematic	Smectic TEMPERATURE	solid solid

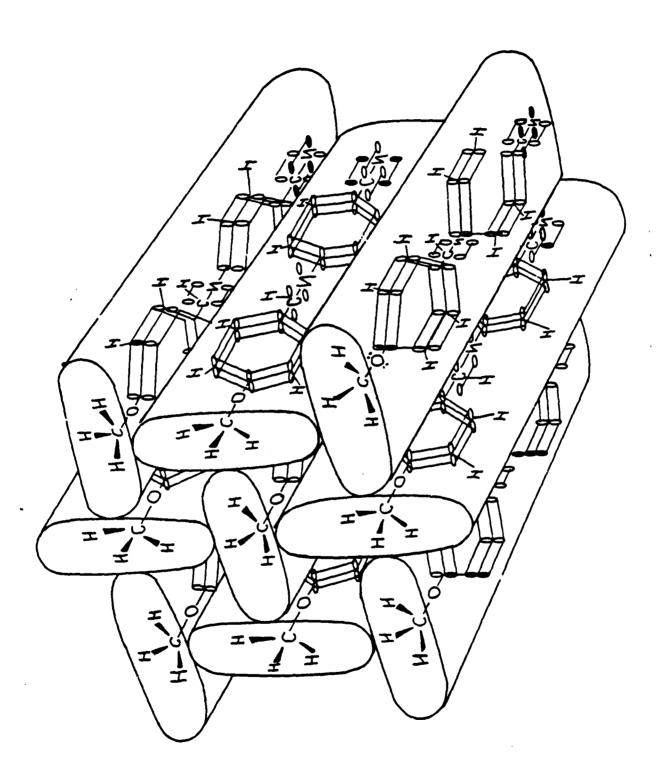
NEMATIC: Orientation Order

SMECTIC: Orientation & Layer Order







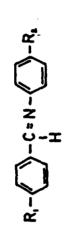


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_ 1

Nonlinear Studies of Schiff Bases

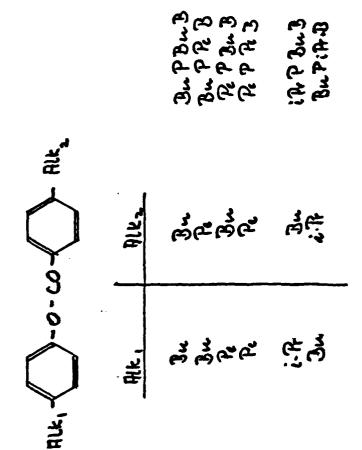




Sample	Color	ج. م	π. •	P _C (kW) at 532 nm	P _c (kW) (cm/GW) at at 532 nm 532 nm	n ₃ x10 ³³ (esu) at 1064 nm
MEBBA	Orange	CH, C,H,	C,H,	74.1	.55±.05	149
ETBBA	Light Yellow	C'H,	C,H	118	.5 ±.05	17±2
IPBBA	Light	с,н, с,н,	C,H,	811	.5 ±.05	13±2
BBIPA	Orange	C,H, C,H,	с,н,	7±1	.5 ±.05	12±2
PEBBA	Orange	C,H,, C,H,	C,H,	111	.55±.05	14±2
ଅ'	Clear			8±1	Small	130

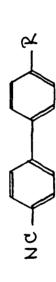
SUBSTITUTED PHENYL BENZOATES





CYANO BIPHENYL DERIVATIVES





Си, -Си,-Си-Си,-Си,

> €7 "

-CH2-CH-CH2-CH3-CH3

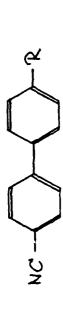
-CH2-CH2-CH3-CH3

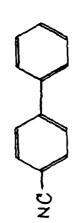
-CHI-CHI-CHI-CHI-CHI

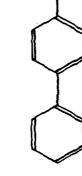
-0 -CH2-CH2-CH2-CH2-CH3

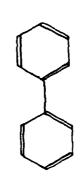
PRECURSORS AND ANALOGUES

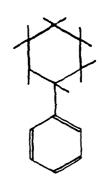


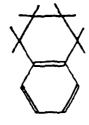














CENTER FOR NIGHT VISION AND ELECTRO-OPTICS LIQUID CRYSTAL ELECTRO-OPTIC SHUTTER

LIQUID CRYSTAL E-O SHUTTER

- BACKGROUND
- NEED FOR CHOPPER
- PRESENT SOLUTIONS
- METAL TOOTH WHEEL: ON/OFF
- GERMANIUM SPIRAL: FOCUS/DEFOCUS
- DISADVANTAGES
- PROPOSED SOLUTION
- LINE SCAN CHOPPER
- DESIRED FEATURES
- PRINCIPLE OF OPERATION
- PROGRESS: DR I. C. KOO, PENN. STATE
- CONCLUSIONS
- PROBLEMS
- APPROACHES

LINE SCAN CHOPPER-DESIRED FEATURES

OPERATES BY FORWARD SCATTERING, NOT TRANSMISSION REDUCTION

WIDE ACCEPTANCE ANGLE: 40° FULL ANGLE

ELECTRICALLY LINE ADDRESSABLE

LARGE ARRAY SIZE: 0.5" SQUARE

• LINE WIDTH: <100 MICRON

LOW INSERTION LOSS: <20%

BROADBAND OPERATION: 8-12 MICRON

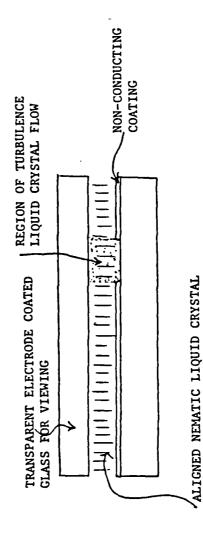
• SWITCHING TIME: <1 ms, ON AND OFF

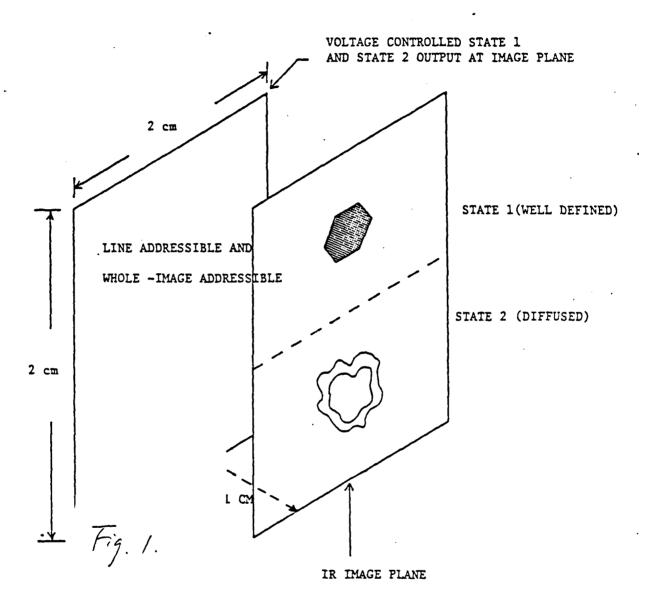
• FORWARD SCATTERING: >95% INTO ANNULUS 10 LINES DIAMETER

• OPERATING TEMPERATURE: -20°C TO +50°C

PRINCIPLE OF OPERATION

- DYNAMIC SCATTERING IN NEMATIC LIQUID CRYSTAL
- APPLIED E FIELD INDUCES TURBULENT MOTION
- MOTION CAUSES OPTICAL SCATTERING





E MODULATOR

LIQUID CRYSTAL CANDIDATES

- NEGATIVE ANISOTROPIC DIELECTRIC NEMATICS
- E-7, ZLI-1132, NP-5: HIGH \triangle n, POSITIVE $\triangle \epsilon$
- ZLI-3381, ZLI-2806: LOW \triangle n, NEGATIVE \triangle ϵ
- CHOSE MIXTURE OF E-7 AND ZLI-3381
- CHARACTERIZE IR BEHAVIOR
- USE IN TEST CELL

•

9

EM INDUSTRIES

ASSOCIATE OF E.MERCK DARMSTADT WEST GERMANY

ADVANCED CHEMICALS DIVISION

ZLI-3381

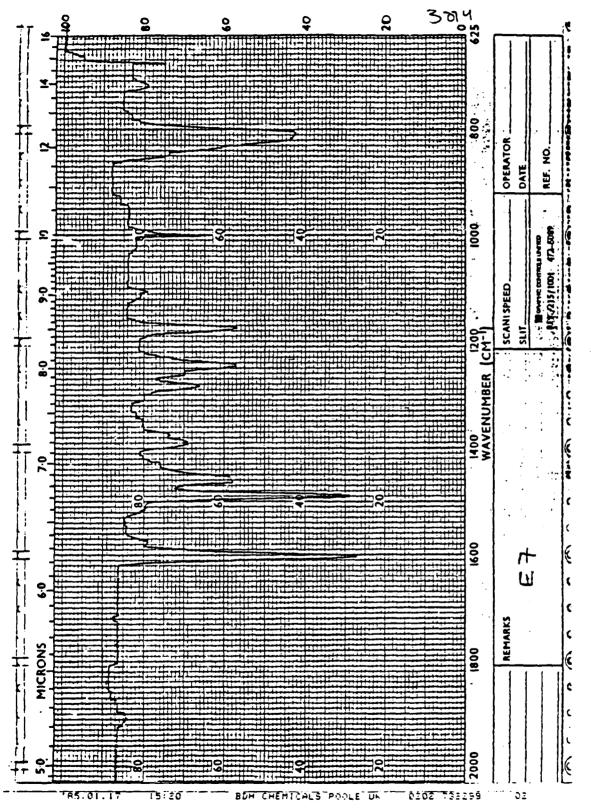
PRELIMINARY DATA SHEET

ALTERNATIVE TO ZLI-2585 AND ZLI-2806

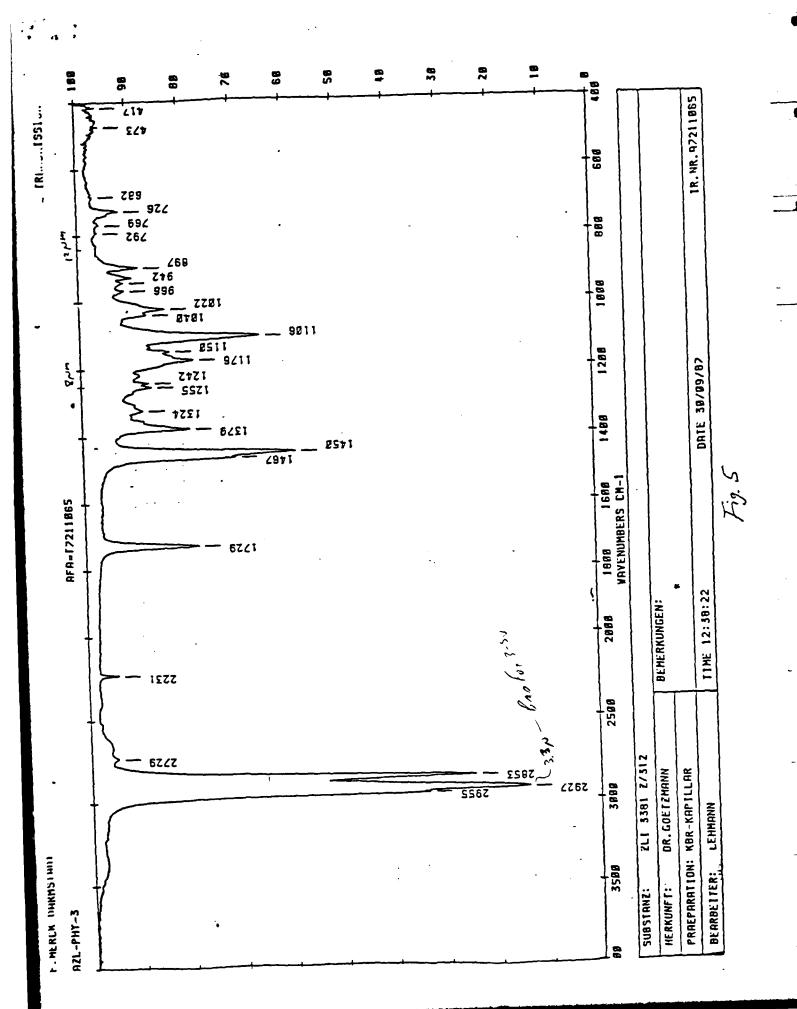
PROPERTIES:

S - N		<-30	оС
CLEARING POINT		84	o C
VISCOSITY	20 °C 0 °C -20 °C -30 °C -40 °C	51 175 977 3000 -	mm2 s-1 mm2 s-1 mm2 s-1 mm2 s-1 mm2 s-1
DIELECTRIC ANISOTROPY $\Delta \epsilon$ (20 °C, 1kHz) $\epsilon_{ }$		-4.6 3.5 8.1	
OPTICAL ANISOTRO (20 °C. 589 nm)		0.042 1.516 1.474	
THRESHOLD VOLTAGE (V (10, 0, 20))		1.8 (DAP)	V
TEMP.DEPENDENCE (0 - 40 °C)	dV/dT	- -	%/°C

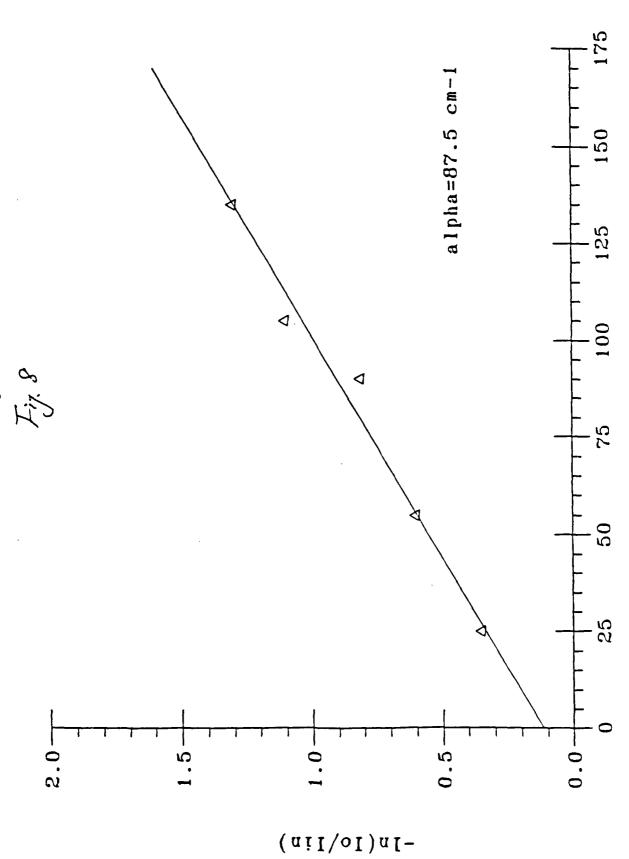
11APR86



1 × 6



EM Chemicals ZLI3381 Absorption Data at 10.6 Microns



sample thickness (microns)

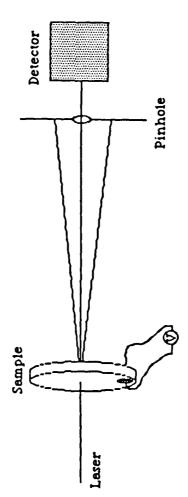
EXPERIMENTAL RESULTS

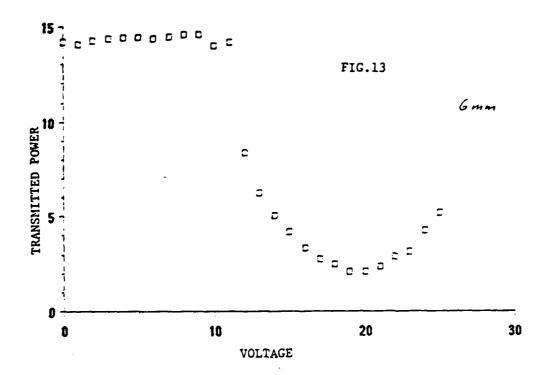
- CELLS USING Ge AND ZnSe WERE FABRICATED (1" x 1")
- ACCEPTANCE ANGLE LARGE: >40°
- "OPTIMUM" THICKNESS ON ORDER OF 20 µm YIELDS ≈ 18% ABSORPTION
- TURBULENCE SIZE DEPENDENCE ON VOLTAGE DETERMINED
- DYNAMIC SCATTERING DEFOCUSING DEMONSTRATED WITH CO₂ LASER
- RESPONSE TIMES MEASURED
- SCATTERING TURN ON ≈ 1 ms
- SCATTERING TURN OFF < 100 ms

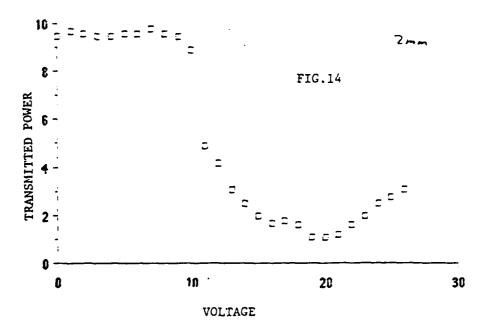
TURBULENCE SIZE VOLTAGE DEPENDENCE

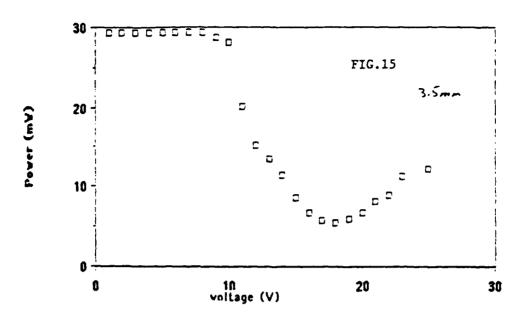
	25 µm Sample
Voits	Turbulence size
10	40 µm x 80 µm
13	40 % 60
3.00	34 % 40 24 % 32
20	20 2 20
30	16 % 16
40	8 :: 12

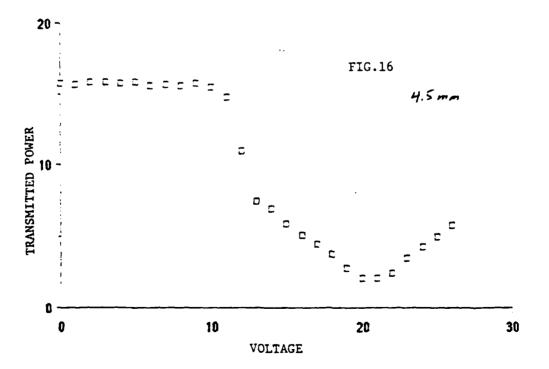
DYNAMIC SCATTERING SETUP

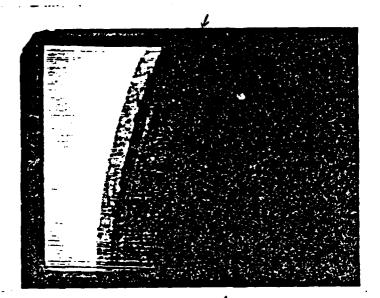






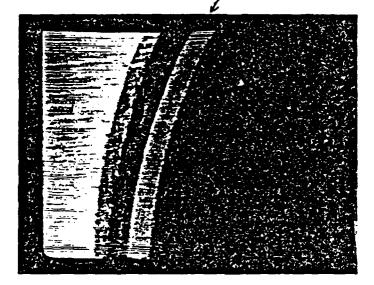






Figures 18.

A



В

1 mm/

C

CONCLUSIONS

- TURN OFF TOO SLOW: 100 ms → 1 ms
- SIZE EFFECTS
- E FIELD EFFECTS
- FIELD CRYSTAL MIXTURE NEEDS OPTIMIZING
- ELECTRODE EFFECTS NEED CHARACTERIZING
- SCATTERING ANGLES NEED CHARACTERIZING
- MULTI-LINE CELL NEEDS DEMONSTRATION
- INSERTION LOSS
- IMAGE DEGRADATION
- IN GENERAL, PROMISING APPROACH

WORKSHOP

Liquid Crystals for Laser Applications

Night Vision and Electro-Optics Center Fort Belvoir, VA

11 May 1988

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